

What we claim is:

1. An optical structure comprising a plurality of layers with at least two layers having composition variation within each layer, the at least two layers comprising a first layer and a second layer and the plurality of layers comprising a first turning element being at least partially located within the first layer and the second layer wherein the first turning element reflects light between a confined optical pathway within the plane of the first layer and a confined optical pathway within the plane of the second layer.
2. The optical structure of claim 1 wherein at least one of the plurality of layers comprises silicon oxide glass.
3. The optical structure of claim 2 wherein the silicon oxide glass comprises at least one dopant.
- 15 4. The optical structure of claim 1 wherein at least one of the plurality of layers comprises aluminum oxide, titanium oxide, telluride glasses, phosphate ( $P_2O_5$ ) glass, InP, lithium niobate, combinations thereof and doped compositions thereof.
5. The optical structure of claim 1 wherein the first layer comprises a 20 plurality of optical devices integrated within the first layer.
6. The optical structure of claim 5 wherein the second layer comprising a plurality of optical devices integrated within the second layer.
- 25 7. The optical structure of claim 5 wherein at least one of the integrated optical devices of the first layer is selected from the group consisting of optical waveguide/conduit, optical attenuator, optical splitter/coupler, optical filter, optical switch, laser, modulator, interconnect, optical isolator, optical add-drop multiplexer (OADM), optical amplifier, optical polarizer, optical circulator, phase shifter, optical 30 mirror/reflector, optical phase-retarder, optical detector, an electrode contact, an optical grating and combinations thereof.

8. The optical structure of claim 5 wherein the plurality of layers further comprises a thermal conductive layer, a stress reducing layer, an electrical conducting guide or a combination thereof.

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9. The optical structure of claim 1 wherein the at least two layers form an integrated optical circuit comprising a plurality of optical devices located on different layers comprising the first layer and the second layer, the first turning element forming a light pathway from the first layer to the second layer and the optical devices being functionally integrated between the different layers by the first turning element.

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10. The optical structure of claim 9 wherein the at least two layers comprises a third layer, the at least three layers comprising a second turning element, the second turning element deflecting light from within the second layer to the third layer to functionally integrate optical devices within the second layer and the third layer.

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11. The optical structure of claim 9 wherein the first turning element optically connects a first planar waveguide in the first plane with a second planar waveguide in a second plane.

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12. The optical structure of claim 1 wherein the first turning element comprises an angled mirror.

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13. The optical structure of claim 12 wherein the angled mirror is formed by an angled surface of a waveguide forming an interface with a lower index-of-refraction material.

14. The optical structure of claim 13 wherein the lower index-of-refraction material comprises a fluid.

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15. The optical structure of claim 12 wherein the lower index-of-refraction material comprises a glass.

16. The optical structure of claim 12 wherein the lower index-of-refraction 5 material has an index-of-refraction at least about a factor of 1.3 lower than the index-of-refraction of the waveguide material.

17. The optical structure of claim 12 wherein the lower index-of-refraction 10 material comprises an electro-optical material that has an index-of-refraction that is controlled by one or more electrodes that correspondingly turn the mirror on and off.

18. The optical structure of claim 12 wherein the lower index-of-refraction material comprises a thermo-optical material, the structure further comprising a thermal transmission region adjacent the thermo-optical material.

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19. The optical structure of claim 12 wherein the angled mirror comprises an angled surface of a waveguide having an interface with a metal.

20. The optical structure of claim 12 wherein the angled mirror comprises 20 alternating layers of material with different indices-of-refraction.

21. The optical structure of claim 12 wherein the first turning element further comprises a second angled mirror along an optical pathway formed from the first angled mirror wherein the second angled mirror optically connects an optical pathway in a 25 second layer with the first angled mirror.

22. The optical structure of claim 1 wherein the first turning element 30 comprises an optical taper forming an optical pathway of a higher index-of-refraction materials surrounded by a cladding material with a lower index-of-refraction wherein the optical pathway involves a gradual turn from the first layer out of the plane of the first layer.

23. An optical structure comprising a plurality of layers with at least two layers having composition variation within each layer, the at least two layers comprising a first layer and a second layer and the plurality of layers comprising a turning element being at least partially located within the first layer wherein the turning element comprises an optical taper forming an optical pathway of a higher index-of-refraction materials surrounded by a cladding material with a lower index-of-refraction wherein the optical pathway involves a gradual turn from the first layer out of the plane of the first layer.

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10 24. The optical structure of claim 23 wherein the taper is optically connected to a first planar waveguide in the first layer and a second planar waveguide in the second layer.

15 25. The optical structure of claim 24 wherein the optical taper, the first planar waveguide and the second planar waveguide have approximately the same index-of-refraction.

20 26. A method for forming a patterned coating on a surface, the method comprising:

a) reacting a reactant flow to form product particles in a product stream; and

b) directing the product particle stream through a first discrete mask at a surface to form the patterned coating on the surface, the first discrete mask not being bonded to the surface.

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27. The method of claim 26 wherein the reactant flow intersects a radiation beam to form a reaction zone at which the product particle stream is formed.

30 28. The method of claim 27 wherein the radiation beam is generated by an infrared laser.

29. The method of claim 26 wherein the reactant stream is formed by an inlet nozzle that is elongated in one dimension relative to the orthogonal dimension.

30. The method of claim 29 wherein the inlet nozzle has an aspect ratio of the  
5 elongated dimension to the orthogonal dimension of at least about 5.

31. The method of claim 29 wherein the inlet nozzle has an elongated dimension longer than a width across the surface resulting in the formation of a coating across the entire surface with one linear pass of the surface through the product particle  
10 stream.

32. The method of claim 26 wherein the reactant stream comprises vapor/gas precursors of the product particles.

15 33. The method of claim 26 wherein the reactant stream comprises aerosol precursors of the product particles.

34. The method of claim 33 wherein the reactant stream further comprises vapor/gas precursors of the product particles.

20 35. The method of claim 26 wherein the reactant stream comprises a silicon precursor.

36. The method of claim 35 wherein the reactant stream further comprises a  
25 silicon oxide glass dopant precursor.

37. The method of claim 26 wherein the patterned coating consolidates into optical material.

30 38. The method of claim 37 wherein the optical material comprises a glass.

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39. The method of claim 37 wherein the optical material comprises a crystalline material.

40. The method of claim 39 wherein the crystalline material comprises a  
5 polycrystalline material.

41. The method of claim 39 wherein the crystalline material comprises a single crystalline material.

10 42. The method of claim 37 further comprising consolidating the patterned coating to form an optical material.

15 43. The method of claim 26 wherein the first discrete mask comprises a sheet with a plurality of cut-outs through which the product particle stream pass to form the patterned coating.

44. The method of claim 26 further comprising removing the first discrete mask to leave the patterned coating separate from the mask.

20 45. The method of claim 44 further comprising:  
a) placing a second discrete mask adjacent the surface;  
b) reacting a reactant flow to form product particles in a product stream wherein the product particles, when the second discrete mask is located adjacent the surface, are different from the product particles when the first discrete mask is located adjacent the surface; and  
25 c) directing the product particle stream through the second discrete mask at a surface to form an additional patterned coating on the surface, the second discrete mask not being bonded to the surface.

46. The method of claim 45 wherein the second discrete mask forms a pattern complementary to at least a portion of the patterned coating formed by the first discrete mask.

5 47. The method of claim 44 wherein the first discrete mask comprises at least two sets of openings corresponding to patterned coatings each having sufficient size to cover the substrate and wherein the directing of the product particles through the first discrete mask comprises directing the particles through a first of the at least two sets of openings, the method further comprising translating the first discrete mask to align a 10 second of the at least two sets of openings over the substrate and depositing product particles with a different composition from the composition of the product particles directed through the first of the at least two sets of openings.

15 48. The method of claim 27 wherein the first discrete mask comprises two separable masks placed adjacent each other to form the first discrete mask for directing the particle stream.

20 49. A method for forming coating(s) comprising a first coating on a surface with varying composition in the first coating at different locations along the surface, the method comprising:

a) reacting a reactant flow to form a product particle stream; and  
b) directing the product particle stream at a surface to form each of the coating(s), wherein the first coating is formed over at least about 5 square centimeters of the surface and forms a pattern of different compositions at different locations and is 25 formed in less than about 5 minutes.

50. The method of claim 49 wherein the product particles are directed through a mask.

30 51. The method of claim 49 wherein the product particle stream and the surface are moved relative to each other and wherein composition of the product particle

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stream is changed over time resulting in deposition of different compositions at different locations along the surface.

52. The method of claim 49 wherein the product particle stream is produced by a plurality of nozzles with different reaction precursors flowing to the nozzles, wherein the nozzles are oriented to deposit different compositions at different locations on the surface.

53. The method of claim 49 wherein the first coating is deposited in less than about 1 minute.

54. The method of claim 49 wherein the first coating is deposited in less than about 15 seconds.

15 55. The method of claim 49 wherein the first coating has a thickness of at least about 100 nanometers.

20 56. The method of claim 49 wherein the coating(s) comprise a second coating and wherein the second coating is formed over at least about 5 square centimeters of the surface and forms a pattern of different compositions at different locations and is formed in less than about 5 minutes.

57. The method of claim 49 wherein the product particle stream is altered while directing the product particle stream at the surface.

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58. The method of claim 56 wherein the coating process forms a material with a gradual composition transition from a first composition to a second composition.

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59. A method for forming at least one coating on a surface with varying composition areas at different locations along the surface, the method comprising:

- a) reacting a reactant flow to form a product particle stream; and

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b) directing the product particle stream at a surface wherein the product particle stream sequentially coats portions of the surface and wherein the product particle stream is altered during the coating process to deposit different product particle compositions at different locations along the surface.

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60. The method of claim 59 wherein the reactant flow intersects a radiation beam to form a reaction zone at which the product particle stream is formed.

61. The method of claim 59 wherein the reactant stream is formed by an inlet nozzle that is elongated in one dimension relative to the orthogonal dimension, the inlet nozzle having an elongated dimension longer than a width across the surface resulting in the formation of a coating across the entire surface with one linear pass of the surface through the product particle stream.

10 15 62. The method of claim 59 wherein the reactant stream comprises a silicon precursor.

63. The method of claim 59 wherein the reactant stream comprises vapor/gas precursors of the product particles.

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64. The method of claim 63 wherein the composition of the reactant stream is varied by adjusting the flow through mass flow controllers.

65. The method of claim 59 wherein the reactant stream comprises aerosol precursors of the product particles.

25 66. The method of claim 65 wherein the composition of the reactant stream is varied by adjusting the flow to an aerosol generator that produces at least a portion of the aerosol precursors of the reactant stream.

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67. The method of claim 59 wherein the coating consolidates into optical material.

68. The method of claim 59 wherein the composition variation results from 5 adjusting dopant levels relative to an approximately fixed host material composition.

69. The method of claim 59 wherein the composition variation comprises approximately step-wise changes.

10 70. The method of claim 59 wherein the composition variation involves gradual composition changes.

71. The method of claim 59 wherein the surface and the reactant flow/product particle stream are moved relative to each other to coat the surface.

15 72. The method of claim 59 wherein a discrete mask is used to selectively direct the particle stream to portions of the surface to coat the surface.

73. The method of claim 73 wherein the discrete mask is moved relative to the 20 surface.

74. The method of claim 59 wherein the directing of a product particle stream at a surface comprises depositing a plurality of product particle streams having different particle compositions from each other.

25 75. The method of claim 59 wherein the reactant stream comprises an inert gas.

76. The method of claim 59 wherein the composition of the product particles 30 is varied by adjusting the concentration of inert gas in the reactant stream.

77. The method of claim 59 wherein the composition of the product particles is varied by adjusting the intensity of the radiation beam.

78. The method of claim 59 wherein the substrate and product particle stream are moved relative to each other in a first direction to coat a portion of the surface and in 5 an opposite direction to coat another portion of the surface.

79. The method of claim 59 further comprising blocking the flow of the particle stream with a shutter between two deposition periods wherein particles are 10 deposited onto the substrate surface.

80. The method of claim 59 wherein the at least one coating is formed in less than about 5 minute.

15 81. The method of claim 59 wherein the at least one coating is formed in less than about 1 minute.

82. The method of claim 59 wherein the at least one coating is formed in less than about 15 seconds.

20 83. An optical material comprising an optical transition material, wherein the optical transition material has a thickness of no more than about 300 microns and comprises a gradual composition transition from a first composition and a second composition.

25 84. The optical material of claim 83 wherein the optical transition material has a thickness no more than about 150 microns.

30 85. The optical material of claim 83 wherein the optical transition material has a thickness no more than about 50 microns.

86. The optical material of claim 83 wherein the optical transition material comprises a plurality of layers with step-wise variation in composition, each layer having a thickness less than about 100 microns.

5 87. The optical material of claim 83 wherein the optical transition material comprises a plurality of layers with step-wise variation in composition, each layer having a thickness less than about 25 microns.

10 88. The optical material of claim 87 wherein each layer within the optical transition material has a thickness less than about 20 microns.

89. The optical material of claim 87 wherein each layer within the optical transition material has a thickness less than about 10 microns.

15 90. The optical material of claim 86 wherein the optical transition material comprises at least 3 layers.

91. The optical material of claim 86 wherein the optical transition material has from 4 layers to 12 layers.

20 92. The optical material of claim 86 wherein the layers of the optical transition material have approximately equal thickness.

25 93. The optical material of claim 83 wherein the gradual composition transition is an approximately continuous composition transition.

94. The optical material of claim 83 wherein the optical transition material comprises silicon oxide glass with varying dopant levels.

95. The optical material of claim 83 wherein the first composition comprises an optionally doped silicon oxide and the second composition comprises doped silicon oxide with a different composition than the first composition.

5 96. The optical material of claim 95 further comprising a core material adjacent the second composition.

97. The optical material of claim 96 further comprising an over-cladding material adjacent the core material.

10 98. The optical material of claim 83 further comprising a silicon substrate and a layer of an optical silicon compound wherein the optical transition material is located between the silicon substrate and the optical silicon compound and wherein the first composition comprises silicon and the second composition comprises the optical silicon compound.

15 99. The optical material of claim 98 wherein the optical silicon compound is selected from the group consisting of  $(\text{SiO}_2)$ , SiC, SiN, combinations thereof and doped compounds thereof.

20 100. The optical material of claim 83 wherein the optical material has a surface area of at least about  $1 \text{ cm}^2$ .

101. An optical structure comprising the optical material of claim 83.

25 102. An optical waveguide comprising a first cladding layer of optical material, a second cladding layer of optical material and a core of optical material, which is adjacent the first cladding layer and the second cladding layer and which has a higher average index-of-refraction than that of each of the cladding layers, wherein at least one of the cladding layers  
30 comprises a lower index-of-refraction region adjacent the core layer, the lower index-of-

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refraction layer having an average index-of-refraction lower than the average index-of-refraction of the at least one of the cladding layers.

103. The optical waveguide of claim 102 wherein the lower index-of-refraction  
5 region has an average index-of-refraction at least about 0.0005 units less than the average  
index-of-refraction of the at least one of the cladding layers.

104. The optical waveguide of claim 102 wherein the lower index-of-refraction  
region has a thickness from about 7% to about 25% of the thickness of the core material.

10 105. The optical waveguide of claim 102 wherein both cladding layers comprises  
a lower-index-of-refraction region adjacent the core layer, each such region having an  
average index-of-refraction lower then than the average index-of-refraction of the  
corresponding cladding layer.

15 106. A method of forming an optical structure comprising an optical transition  
material that comprises a gradual composition transition at a location on a substrate from  
a first composition and a second composition, the method comprising:

a) reacting a reactant flow to form a product particle stream; and

20 b) directing the product particle stream at a surface wherein the  
product particle stream is altered during the coating process to form a material with the  
gradual composition transition.

107. The method of claim 106 wherein the reactant flow intersects a radiation  
25 beam to form a reaction zone at which the product particle stream is formed.

108. The method of claim 106 wherein the product particle stream is  
simultaneously directed at the entire location on the substrate and the composition of a  
reactant stream is continuously changed to alter the composition of the deposited particles.

109. The method of claim 106 wherein the optical transition material comprises a plurality of sublayers, and wherein the composition of the product particle stream is altered between the deposition of each sublayer.

5 110. The method of claim 106 wherein the product particle stream sequentially coats additional portions of the surface.

111. The method of claim 106 wherein the optical transition layer comprises at least one layer and wherein the at least one layer is formed in less than about 5 minutes.

10 112. The method of claim 111 wherein the at least one layer is formed in less than about 1 minute.

15 113. The method of claim 111 wherein the at least one layer is formed in less than about 15 seconds.

114. A coating apparatus comprising:  
a plurality of elongated reactant inlets defining a plurality of reactant stream paths;  
optical elements forming one or more light paths intersecting the reactant stream paths at a plurality of reaction zones with a product stream path continuing from the reaction zones; and  
a substrate intersecting the product stream paths with each of the product stream paths directed to separate locations on the substrate.

25 115. The coating apparatus of claim 114 wherein at least two of the plurality of reactant inlets are fed by reactant precursor sources to provide different reactant stream compositions.

30 116. The coating apparatus of claim 114 wherein at least two of the plurality of noncircular reactant inlets are adjacent each other.

117. The coating apparatus of claim 114 wherein at least two of the plurality of noncircular reactant inlets are angled in a spaced apart configuration to deposit respective product particles at adjacent locations on the substrate.

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118. A method for coating the surface of a substrate, the method comprising:  
a) reacting a plurality of reactant flows to form a plurality of product particle streams, wherein at least two of the plurality of product particle stream have different particle compositions from each other; and

10 b) simultaneously depositing the at least two of the plurality of product particle streams on a surface wherein the product particle streams are directed to different locations on the substrate surface.

119. The method of claim 118 wherein the plurality of product particle streams comprises two product particle streams that contact adjacent locations on the substrate surface.

120. The method of claim 119 wherein the two product particle stream overlap at the substrate surface.

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121. The method of claim 119 wherein at least one of the product particle streams is elongated in one dimension relative to the orthogonal direction and wherein the at least one of the product particle streams is aligned with axes oriented along the elongated direction of the product particle streams being generally parallel.

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122. A coating apparatus comprising:  
a) a reactant inlet defining a reactant stream path;  
b) optical elements forming a light path intersecting the reactant stream paths at a reaction zone with a product stream path continuing from the reaction zone;  
30 c) a substrate intersecting the product stream path directed to a substrate; and

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d) a shutter that can selectively close to block the product stream path from reaching the substrate.

123. A method for coating the surface of a substrate, the method comprising:

5 a) reacting a reactant flow to form a product particle stream directed toward a substrate surface;

b) blocking the product particle stream with a shutter to prevent coating of the substrate surface; and

10 c) opening the shutter a first period of time to deposit the product particle stream on a surface of the substrate.

124. The method of claim 123 further comprising opening the shutter a second period of time to deposit product particles onto the substrate surface wherein the substrate is moved relative to product particle stream between the first period of time and the second period of time.

15 125. The method of claim 123 further comprising opening the shutter a second period of time to deposit product particles onto the substrate surface wherein the product particle stream is changed between the first period of time and the second period of time.

20 126. An optical device comprising a first cladding layer of optical material, a second cladding layer of optical material and a core of optical material, which is adjacent the first cladding layer and the second cladding layer and which has a higher index-of-refraction than the cladding layers, wherein one of the cladding layers has a localized band of tap material having an index-of-refraction intermediate between the core layer and the average index-of-refraction of the cladding layer with the localized band intersecting the core material, the tap material providing for the leakage of some light intensity into the tap material when light is transmitted through the core.

25 127. The optical device of claim 126 wherein the core forms a coupler/splitter with one optical path being optically coupled to a plurality of optical paths.

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128. The optical device of claim 127 wherein the tap material intersects the plurality of optical paths.

5 129. The optical device of claim 126 wherein the tap material is optically integrated with an optical detector.

10 130. An integrated optical circuit comprising a vertical cavity surface emitting laser, a planar waveguide and a turning element optically connecting the planar waveguide and the vertical cavity surface emitting laser with emissions being directed approximately perpendicular to the plane of the waveguide.

15 131. The integrated optical circuit of claim 130 wherein the turning element is a mirror.

132. The integrated optical circuit of claim 130 wherein the turning element is a taper.

20 133. The integrated optical circuit of claim 130 wherein the turning element is a photonic crystal.

25 134. A planar optical amplifier comprising an under-cladding layer; a mid-cladding layer; an over-cladding layer; a signal core adjacent to the under-cladding layer and the mid-cladding layer; and a pump-guide core adjacent to the mid-cladding layer and the over-cladding layer; the signal core having a higher average index-of-refraction than the under-cladding layer and the mid-cladding layer and comprising a gain region that comprises a composition that absorbs light in a selected region of the electromagnetic spectrum; the pump-guide core having a higher average index-of-refraction than the mid-cladding layer and the over-cladding layer; and the mid-cladding layer having a transmission region overlapping the gain region wherein the transmission

region has an index-of-refraction higher than the average index-of-refraction of the mid-cladding layer.

135. The planar optical amplifier of claim 134 wherein the pump-guide core  
5 comprises a transfer region adjacent the gain region in a direction perpendicular to a  
plane orienting the structure in which the transfer region has an index-of-refraction less  
than the average index-of-refraction of the pump-guide core.

136. A continuously variable optical attenuator comprising a first cladding  
10 layer; a second cladding layer that is thermally conductive; a third cladding layer; a  
pump-core adjacent to the second cladding layer and the third cladding layer, the pump  
core having an index-of-refraction higher than the second cladding layer and the third  
cladding layer and the pump-core comprising an absorption region that absorbs a selected  
region of the electromagnetic spectrum, and an active-core between the first cladding  
15 layer and the second cladding layer, the active core comprising a thermally sensitive  
region adjacent at least a portion of the absorption region, the thermally sensitive region  
comprising a material having an index-of-refraction that varies with temperature.

137. A continuously variable optical switch comprising an interferometer  
20 having two coupled waveguides that join at a directional coupler, one of the coupled  
waveguides comprising a continuously variable optical attenuator of claim 118.

138. A monolithic planar optical circuit comprising a first planar optical  
waveguide, a second optical waveguide and a mirror optically connecting the first planar  
25 waveguide and the second planar waveguide, wherein the mirror comprises an elemental  
metal forming a mirror surface positioned to reflect light between the first planar  
waveguide and the second planar waveguide.

139. The monolithic planar optical circuit of claim 138 wherein the first planar  
30 optical waveguide and the second optical planar waveguide are within the same layer of  
the monolithic planar optical circuit.

140. The monolithic planar optical circuit of claim 138 wherein the first planar optical waveguide and the second optical planar waveguide are in different layers of the monolithic planar optical circuit.

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141. The monolithic planar optical circuit of claim 138 wherein the mirror is partly reflecting.

142. A planar optical circuit comprising a monolithic optical structure having a  
10 first optical device and a second optical device, the first optical device and second optical device being optically connected by a free space optical element embedded within the monolithic optical structure.

143. The planar optical circuit of claim 142 wherein the free space optical element is located in a trench within the monolithic structure between the first optical device and the second optical device.

144. The planar optical circuit of claim 143 wherein the trench is filled with a liquid.

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145. The planar optical circuit of claim 143 wherein the trench is filled with a polymer.

146. A method for forming a coated substrate with the coating comprising a  
25 doped material, the method comprising:

forming a powder coating within a reaction chamber in which the powder is deposited from a stream of product particles formed within the reactor; and

heat treating the powder coating by flowing a fuel and oxygen source within the reactor wherein the reactant stream does not produce particles.

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147. A coated substrate comprising a powder coating on the substrate, the powder having a larger average particle size along a cross section a first distance from the substrate relative to the average particle size along a cross section a second distance from the substrate, the second distant being larger than the first distance.